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A STUDY OF ALTERNATIVE APPROACHES TO PRODUCE OBSCURING SMOKE WITH JP-8 IN VEHICLE ENGINE EXHAUST SMOKE SYSTEMS (VEESS)

INTERIM REPORT
BFLRF No. 263

By

B.R. Wright
D.M. Yost
D.S. Moulton
Belvoir Fuels and Lubricants Research Facility (SwRI)
Southwest Research Institute
San Antonio, Texas

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Studies were conducted to evaluate several approaches to form obscuring smoke from diesel-powered armored equipment using JP-8 fuel in the VEESS system. One approach investigated the idea of removing the more volatile fractions from the fuel using a vehicular-installed fractional distillation unit, thus providing a less volatile portion to be used as the smoke agent. Results of this study did indicate the possibility of using the less volatile 20 percent bottoms portion of the base fuel. A second approach was investigated that used blends of JP-8 fuel and 5 percent crankcase lubricant in either the combustion chamber and/or the air induction system. It was thought that this combination of fuel/lubricant would produce a soot-laden exhaust that would provide nucleation sites for fuel vapor condensation. These results were not successful for the fuel/engine system that was evaluated.

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EXECUTIVE SUMMARY

Problems and Objectives: The changeover from diesel fuel (DF-2) to JP-8 as the fuel for the single-fuel-forward concept has rendered the vehicle engine exhaust smoke system (VEESS) ineffective as a force multiplier. A primary objective of this program was to address several alternatives to solving this problem. These approaches included the evaluation of fractional distillation to remove the more volatile fractions, thus providing a less volatile product for use in the VEESS. A secondary objective was the evaluation of the introduction into the combustion chamber of low concentrations (<5 percent) POL material blended into the fuel. The combustion of less volatile material was intended to saturate the exhaust with soot particles, thus providing increased nucleation sites for improved vapor condensation into smoke droplets.

Importance of Project: The lack of adequate VEESS performance with JP-8 is a major detriment of using JP-8 as the single battlefield fuel. In order to restore the VEESS effectiveness, it is imperative that a successful solution be accomplished.

Technical Approach: This effort focuses on basically two different engineering approaches to the solution of this problem. First, the lower molecular weight, more volatile materials that could cause the vapor not to condense by the dilution of the heavier materials were removed from the fuel.

The second approach was to evaluate the effect of combusting heavier materials like crankcase lubricants to provide increased sooting particles. These sooting particles could then function as nucleation sites for the fuel vapor.

Accomplishments: Fuel fractions from JP-8 were prepared and evaluated as smoke-producing agents using the single-cylinder BFLRF-designed device. Results of these tests indicated that the heavier fractions could be used to produce an obscuring smoke. Computer programs that simulate refinery processes were successfully utilized to define the required parameters for an on-board flash-evaporator distillation unit. Attempts to improve fog formation with induction/combustion of fuel/POL materials proved unsuccessful for the engine and conditions investigated.

Military Impact: Results of the on-board distillation apparatus studies have indicated that a unit capable of providing a smoke-producing agent is possible.

FOREWORD/ACKNOWLEDGMENTS

This work was conducted at the Belvoir Fuels and Lubricants Research Facility (SwRI), Southwest Research Institute, under DOD Contract No. DAAK70-87-C-0043. The project was administered by the Fuels and Lubricants Division, Materials, Fuels, and Lubricants Laboratory, U.S. Army Belvoir Research, Development and Engineering Center, Fort Belvoir, Virginia 22060-5606, with Mr. T.C. Bowen, STRBE-VF, serving as contracting officer's representative and Mr. M.E. LePera, STRBE-VF, serving as technical monitor. This report covers the period of performance from September 1988 to October 1989.

The authors express their appreciation to Mr. Domingo Munoz, Mr. Jim Pryor, Ms. Cindy Sturrock, Ms. Sherry Douvry, and Ms. LuAnn Pierce for their contributions to this report.

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I. INTRODUCTION

Recently the "single-fuel-forward" concept has emerged as a desirable goal for Department of Defense (DOD) and the NATO nations. Under this concept, Aviation Turbine Fuel MIL-T-83133 JP-8 (or MIL-T-5624 JP-5 in some cases) will replace JP-4 in U.S. Air Force and Army aircraft, and will replace VV-F-800 Diesel Fuel in all diesel/turbine-powered ground vehicles/equipment in specified combat theaters. The introduction of JP-8 as the "single fuel forward" has surfaced a major problem in the currently configured vehicle engine exhaust smoke system (VEESS). The operating mechanism for the VEESS is an evaporation/condensation process that uses available exhaust heat to vaporize the fuel; this vaporization is followed by a condensation process of the fuel vapor when cooled in the atmosphere. The resulting condensation produces a fog-like environment due to the buoyancy in air of the approximately 1 μm diameter fuel droplets.

II. APPROACH

This study focused on two distinctly separate engineering concepts, either of which may be used separately or in conjunction with other modifications to the VEESS if required. The first phase of this program evaluated the concept of removing, by distillation, the more volatile components from the JP-8 fuel, resulting in a bottom fraction with a lower vapor pressure. The question and problem of disposal of the more volatile fractions once distilled were not addressed in this report. In this phase, the following questions were addressed:

1. If the more volatile fraction is removed, can the bottom fraction produce a smoke with adequate obscuration and persistency?
2. What percentage of the fuel must be removed to provide this "active" fraction?
3. Is it technically feasible, considering the available facilities such as heat, pressure, etc., to develop an apparatus that will provide this distillation in an acceptable manner?
4. What would be the approximate dimensions and operating requirements for such a distillation device?

Results of the studies addressing these questions are discussed and available data presented in Section III.A.

The second phase evaluated the concept of exhaust enrichment by a small amount of a heavy fluid, such as crankcase lubricant, that had been partially combusted in the engine combustion process. It was intended to investigate the contribution of these heavy smoke/soot particles in the condensation process of JP-8 vapor by providing increased nucleation sites. The introduction of the fuel blends into both the fuel inlet and on the air intake side was evaluated.

III. RESULTS AND DISCUSSION

A. Phase I - Partial Distillation Study

This phase of the program was basically conducted in three tasks:

Task I - Task I of this phase was to utilize a developed computer program to determine the size and operating parameters for a flash distillation unit capable of handling the desired JP-8 feed rate and fogging agent yield rate. These feed rates are determined by the amount of heavy material "bottoms" necessary to provide the required obscuring/fogging agent. As an example, a feed rate of 10 gallons of JP-8 per minute is needed to provide 1 gallon of heavy 10-percent bottoms fogging agent per minute. Therefore, the design guidance incorporates the required size of reactor, available heat, pressure, and cooling necessary to condense the fuel fraction for a desired JP-8 feed rate.

Two computer programs were utilized to simulate and estimate the size and theoretical distillation plate requirements to fractionally distill JP-8 fuel. These programs include the CHEMCAD II from the COADE Company and the SIMSCI from the Simulation Sciences Company. Both programs are routinely applied in refinery design process simulation operations such as evaporation, condensation, and distillation operations.

Calculations were made to determine the feasibility of obtaining a smoke-producing fluid from JP-8. These calculations investigated the use of a flash distillation or a small multistage distillation unit. Heat required to operate the distillation unit would be extracted from the engine exhaust. Based on stoichiometry, the available heat was approximated and compared to the heat required for various distillation rates. The distillations were simulated using COADE's CHEMCAD II software, which was used to calculate the properties of the various fractions and the required heat input. For these calculations, it is assumed that the heat would be available from a 500-hp engine consuming approximately 200 pounds of fuel per hour and producing about 36.500 standard cubic feet of exhaust gases per hour. At 600°F (315°C) exhaust temperature, approximately 0.695 M Btu/hr are removed when the exhaust is cooled to 100°F (38°C). If the starting exhaust temperature is 1000°F (538°C), 1.05 M Btu/hr are removed when the exhaust is cooled to 100°F (38°C). The desired feed rate of JP-8 fuel to the distillation unit was 10 gallons per minute.

Calculations were made for flash or single-stage distillations with different fractions evaporated. The evaporated fraction would be condensed and used for engine fuel only, while the bottom, nonevaporated fraction would be used for the smoke agent. It is assumed that the turbine-powered M1A1 family of vehicles could burn the recycled, more volatile evaporated fraction of JP-8; however, the acceptability of this fraction for use in the diesel-powered M60/M88 and M2/M3 vehicle families is not known. In general, the cut between high and low boiling fractions improves with increasing number of distillation stages, and a few distillations with up to ten stages were simulated.

TABLE 1 shows the calculated values for D 86 distillation curves as predicted by both the PROCESS and the CHEMCAD programs. These D 86 values were averages from the JP-8 property survey.(1)* The first computer simulation of smoke-agent production was made using Simulation Sciences PROCESS software. The feedstock properties were based on DF-2, and the flowsheet was set up to be energy conservative.

When the second computer simulation of smoke-agent production was made, several changes had occurred. The feedstock properties were based on JP-8 fuel, the flowsheet was set up to use less equipment, and changes in the Southwest Research Institute (SwRI) computer systems

* Underscored numbers in parentheses refer to the list of references at the end of this report.

TABLE 1. Calculated ASTM D 86 Distillation Curves for Smoke-Agent Production Using JP-8

Distillation, vol%	Overhead, °F (°C)		Bottoms (Smoke Agent), °F (°C)	
	PROCESS	CHEMCAD II	PROCESS	CHEMCAD II
IP	328 (164)	325 (163)	339 (171)	350 (177)
5	336 (169)	333 (167)	364 (184)	366 (186)
10	344 (173)	345 (174)	375 (191)	379 (193)
30	366 (186)	362 (183)	398 (203)	404 (207)
50	381 (194)	378 (192)	416 (213)	423 (217)
70	404 (207)	401 (205)	436 (224)	445 (229)
90	438 (226)	438 (226)	467 (242)	474 (246)
95	461 (238)	455 (235)	480 (249)	485 (252)
EP	483 (251)	483 (251)	486 (252)	492 (256)

provided easier access to COADE's CHEMCAD II software than to the PROCESS software. As a check on the effects of the changes other than the feedstock properties, the original PROCESS software problem was rerun substituting the JP-8 properties for the DF-2 originally run, and adjusting the feed rates to match those used in the CHEMCAD II run with 80 percent evaporated.

The results of the PROCESS and CHEMCAD II runs with JP-8 properties are shown in TABLE 1.

The CHEMCAD II results indicated a slightly better separation of high and low boiling components than the PROCESS results. The CHEMCAD II overhead product was about 3° to 5°F lower boiling than the PROCESS overhead, but the CHEMCAD II product was about 4° to 8°F higher boiling than the PROCESS product. The difference was probably due to using different thermodynamic models for the flash evaporation. Several options are available for each software, which are believed to provide satisfactory results, but they are not identical. The thermodynamic models used in the PROCESS run were the Grayson-Streed for the

K-values and Johnson-Grayson for the enthalpies. In the CHEMCAD II run, Soave-Redlich-Kwong models were used for both K-values and enthalpies. The differences in the results were not large, and without confirming experimental data, there is no reason to prefer one result over the other.

Distillation curves were calculated for each of the products. The results of the flash distillations are shown in Figs. 1 through 5. As the percent evaporated increased, the smoke agent contained more of the high boiling material. Using the same data, Fig. 6 compares the distillation properties of the smoke agent produced from the 50-, 70-, and 90-percent evaporation cases and the JP-8 fuel feed stock. Results of two multistage distillations are shown in Fig. 7. The Case 1 distillation provided material boiling above 450°F (232°C) over about 95 percent of its range. Case 2, not shown, was nearly identical to Case 1. Case 3, with fewer stages in the distillation, provided material boiling above 450°F over 80 percent of its range. All the multistage distillations provided significantly more high boiling material than did the flash distillations, which only provided material boiling above 450°F over 30 percent of its range in the best (90-percent evaporated) case.

The heat requirements calculated for each distillation are given in TABLE 2; the feed in each case was assumed to enter the process at 75°F (24°C). No heat losses were assumed, and no credits were taken for feed preheat by heat exchange with the products.

In previous experience, good smoke-producing agents were materials with a high boiling range as best provided by the multistage distillations. However, the heat required by multistage distillation was higher than required by flash distillation. At the desired production rate, the available heat with 1000°F (538°C) exhaust was almost enough, 95 percent, to produce smoke agent with 90-percent evaporation in a flash distillation, and small changes could bring it into balance. Sufficient heat could be made available by increasing the engine fuel rate, reducing the smoke-agent production rate, or by adding heat exchangers to preheat the feed and cool the products. In contrast, the available heat only provided about 57 percent of the heat required for multistage distillation. All the same remedies mentioned for flash distillation would be effective for multistage distillation, but there is further to go.

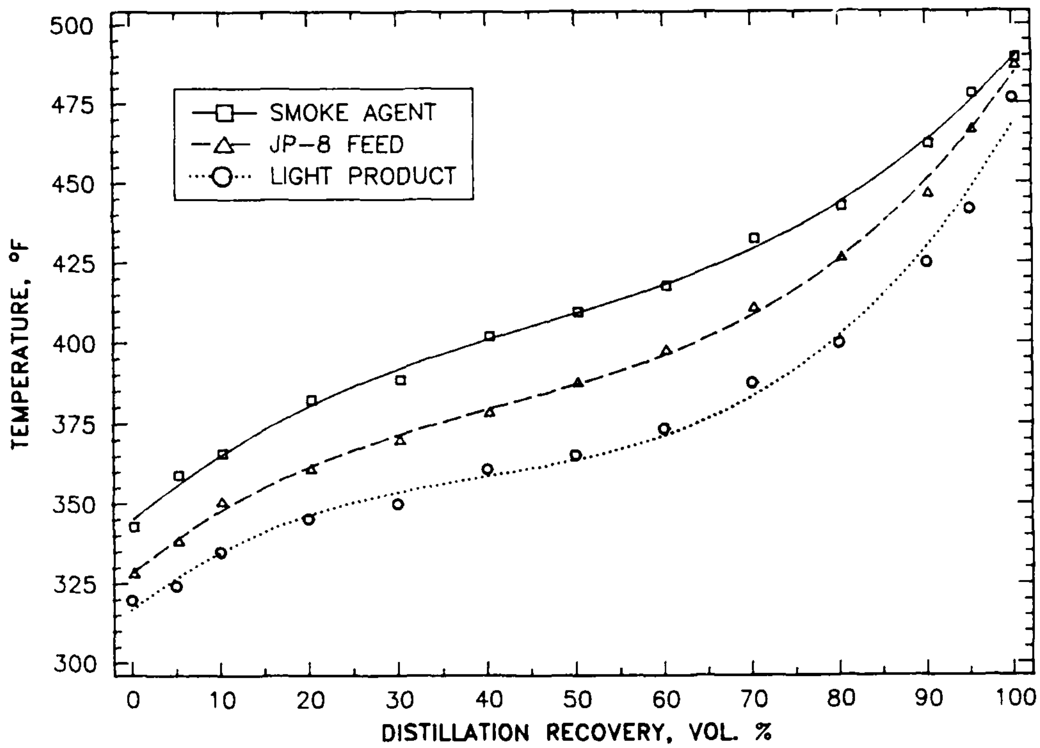

Figure 1. <u>Calculated distillation curves for smoke agent made from JP-8 fuel using flash distillation with 50-percent evaporation</u>

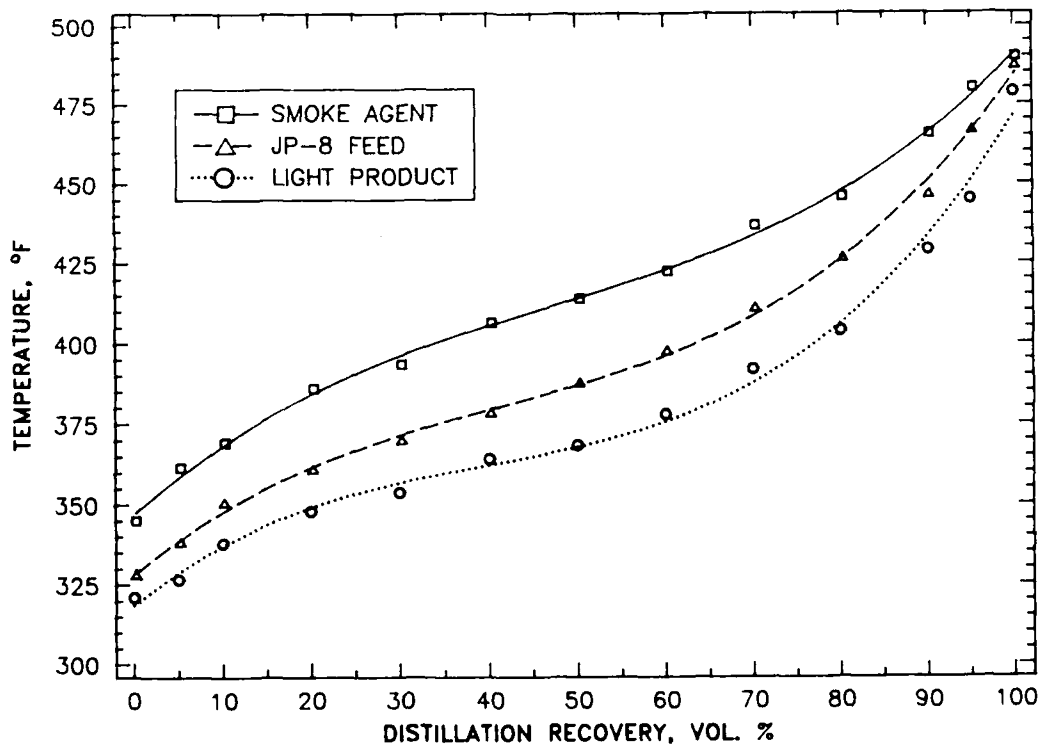

Figure 2. <u>Calculated distillation curves for smoke agent made from JP-8 fuel using flash distillation with 60-percent evaporation</u>

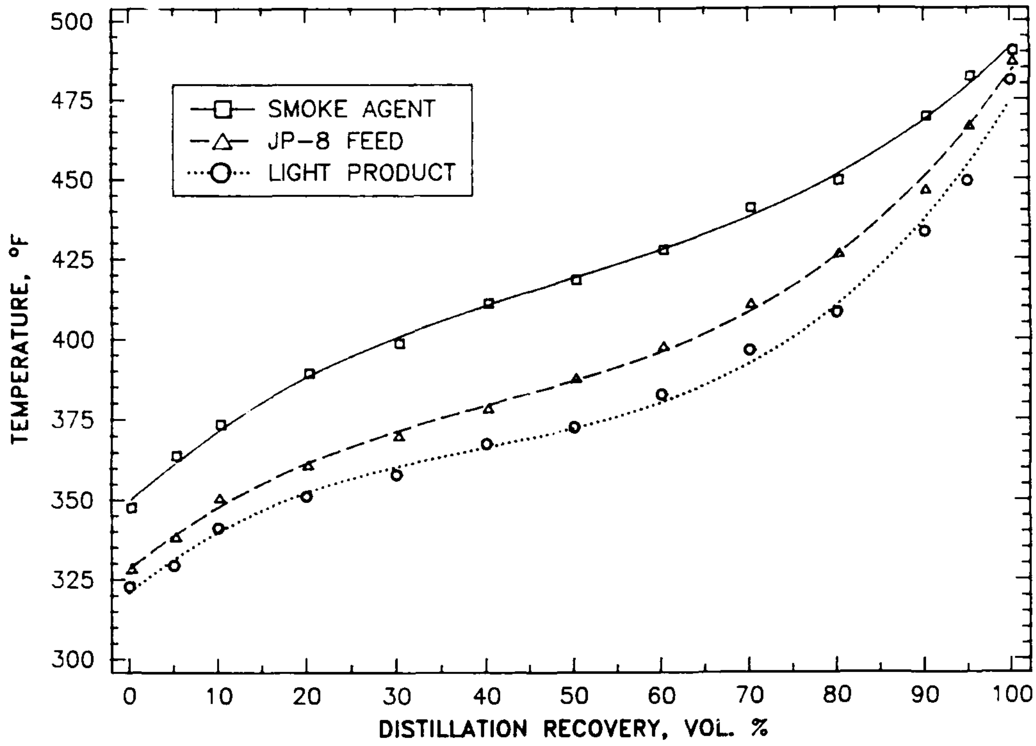

Figure 3. Calculated distillation curves for smoke agent made from JP-8 fuel using flash distillation with 70-percent evaporation

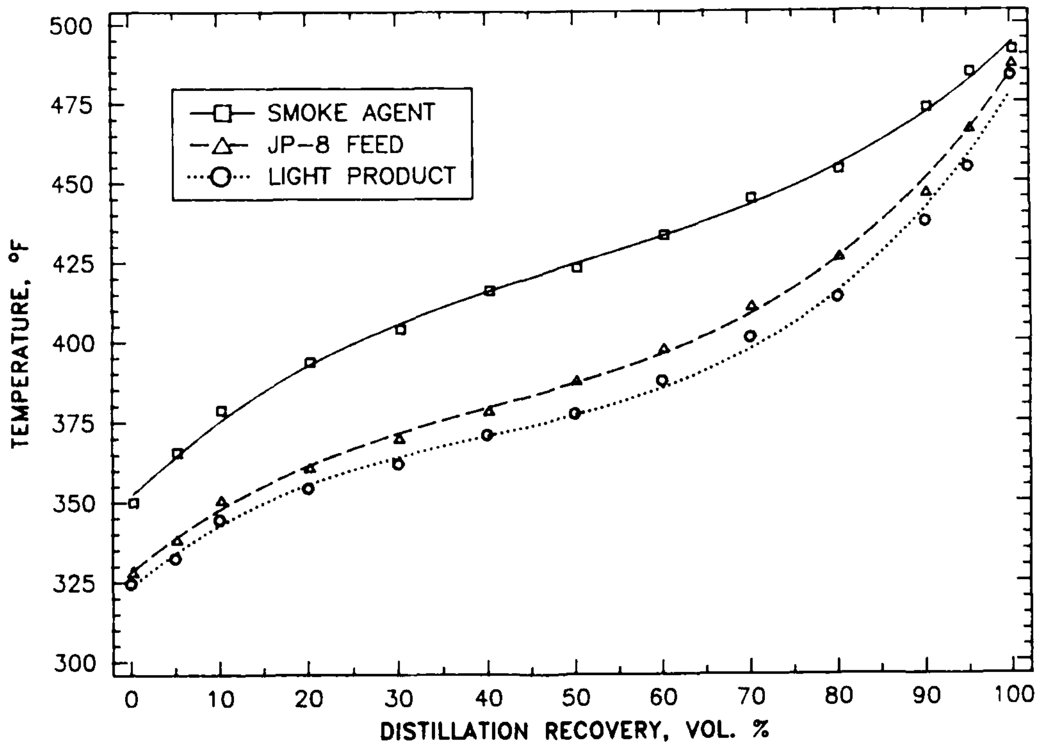

Figure 4. Calculated distillation curves for smoke agent made from JP-8 fuel using flash distillation with 80-percent evaporation

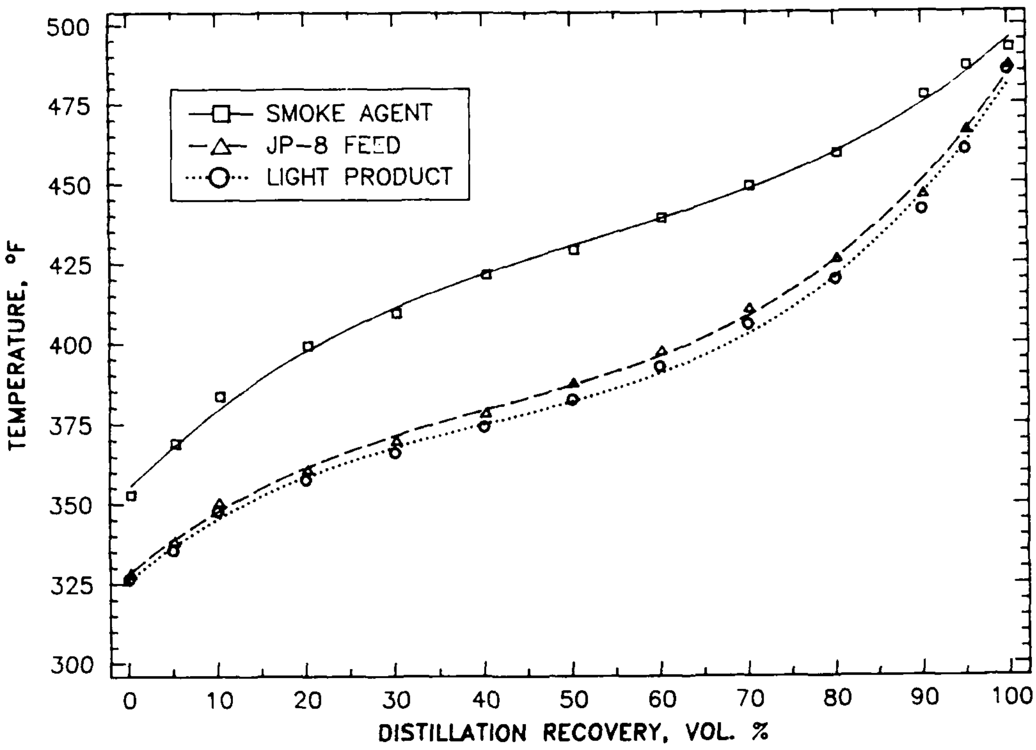

Figure 5. Calculated distillation curves for smoke agent made from JP-8 fuel using flash distillation with 90-percent evaporation

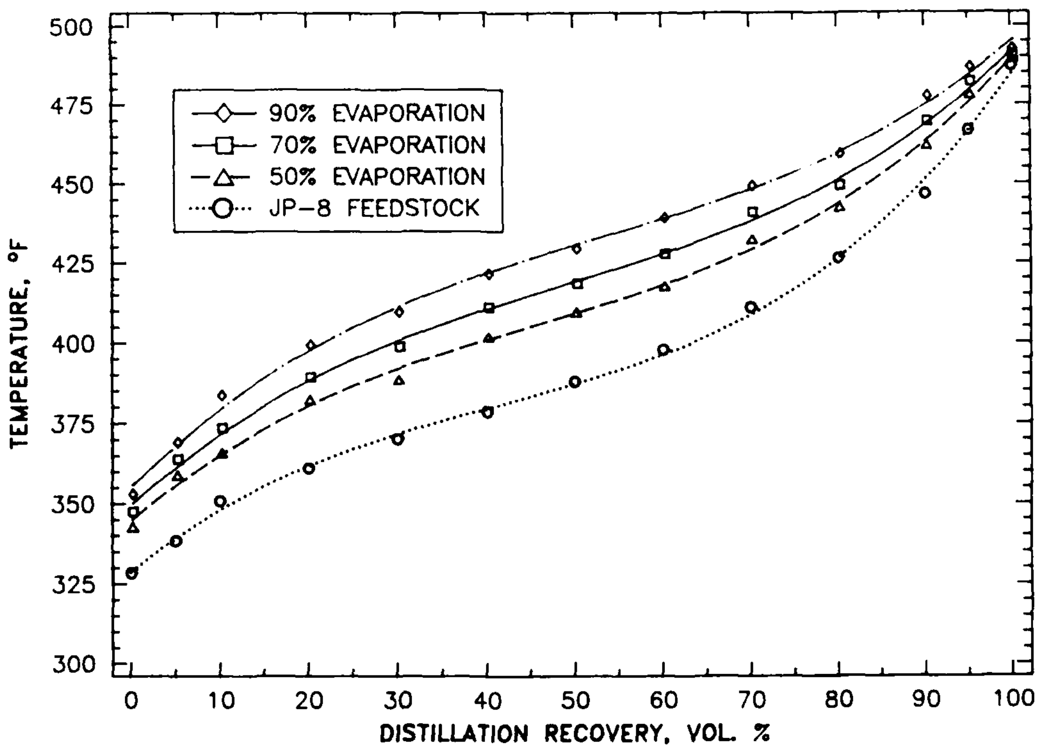

Figure 6. Calculated smoke-agent distillation curves showing effect of flash evaporation fraction on boiling range

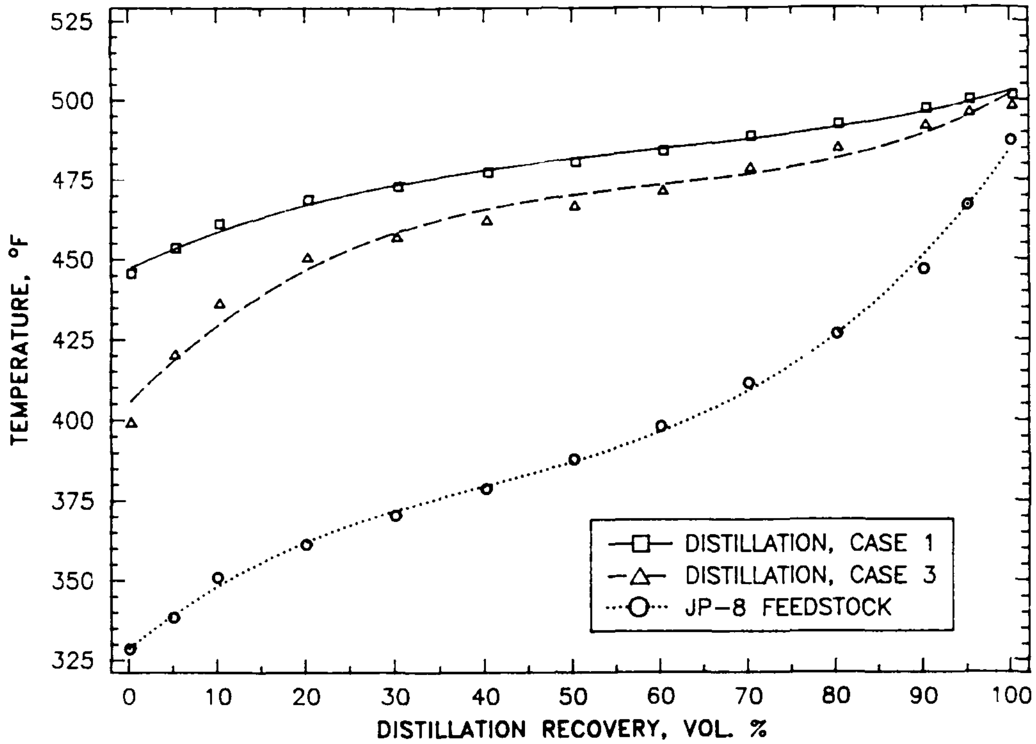

Figure 7. **Calculated smoke-agent distillation curves for smoke agent made from JP-8 fuel using multistage distillations**

Flash evaporator sizing has been estimated using the same CHEMCAD II program parameters previously established for the DF-2 distillation in the fog oil replacement program. However, this program was modified to accommodate the revised parameters projected in the JP-8 program. Basically, these parameters included a higher feed rate (10 gallons per minute), deeper distillation separation (90 percent removed), and a different distillation range (lower than DF-2).

Flash drum sizing to produce a smoke agent from JP-8 was calculated from product literature as follows:

$$\text{Vapor Velocity (V)} = 0.35 \sqrt{\frac{D_L - D_v}{D_v}}$$

TABLE 2. Heat Requirements for Distillations

Type of Distillation[c]	Case No.	Temperature[a], °F (°C)	Fraction Evaporated, %	Heat Requirement[b], M Btu/hr
Flash	50	386 (197)	50	0.890
Flash	60	390 (199)	60	0.944
Flash	70	394 (201)	70	0.999
Flash	80	398 (203)	80	1.05
Flash	90	403 (206)	90	1.11
10-7	1	384 to 500 (196 to 260)	90	1.84
10-8	2	383 to 495 (195 to 257)	89	1.84
6-5	3	383 to 476 (195 to 247)	86	1.80

(a) Flash distillations operate at a single temperature. For multistage distillations, the first temperature is at the top stage and the second is at the bottom stage.

(b) For flash distillations, the heat requirement is the heat in the output streams minus the heat in the fuel stream. For multistage distillations, it is the heat supplied to both the feed preheater and the reboiler of the distillation equipment.

(c) Flash indicates single-stage distillation. When two numbers are given, the first number is the total number of distillation stages, the second number is the feed stage. The top stage in the unit is number one.

where: $D_L = 5.45575 \text{ lb/gal.} \dfrac{1}{0.13368} \text{ ft}^3\text{/gal.}$

$D_L = 40.812 \text{ lb/ft}^3$

D_v = Density of vapor in flash drum

$D_v = 0.27059 \text{ lb/ft}^3$

$$V = 0.35 \sqrt{\frac{40.812 - 0.271}{0.27059}} \; 4.284 \text{ ft/sec}$$

$$= 257.05 \text{ ft/min}$$

$$\text{Feed Rate} = 7028.96 \text{ ft}^3\text{/hr (stream 24)}$$

$$= 117.15 \text{ ft}^3\text{/min}$$

$$= V \cdot \text{Area of flash drum}$$

$$= V \cdot A$$

$$\text{Feed Rate} = 257.05 \text{ ft/min } A$$

$$= 117.15 \text{ ft}^3\text{/min}$$

$$A = 0.4558 \text{ ft}^2$$

$$= \pi R^3$$

$$R = \sqrt{\frac{0.4558}{\pi}}$$

$$R = 0.3809 \text{ ft} = 4.57 \text{ in.}$$

$$ID = 9.14 \text{ in.}$$

Overall flash evaporator size estimate:

D = 10 in.

L = 30 in.

The heat exchanger size required to supply this size flash evaporator has been estimated as follows:

Conditions:
1) JP-8 Feed Rate - 10 gal./min at 75°F (24°C)
2) Exhaust Gas - 1000°F (538°C) at 15 psia, 810 SCFM
3) JP-8 Out Temperature - 386°F (197°C)

From CHEMCAD II estimates:
Area Required = 222 ft^2
Using Tube Areas = 0.1963 ft^2/ft liter
Exchanger Length = 5 to 6 ft, depending on size

Modifications to this size would need to be calculated based on different fuel-in temperature, which could be considerably higher than 75°F. In addition to size, heat exchange maintenance may also be an area of concern. A potential does exist for fouling from soot and corrosive deposits from the engine exhaust and from thermally induced coking deposits in the fuel.

Additional studies are needed in several areas. It is important to establish the relationship between boiling range and smoke-agent quality. That information can be used in deciding what kind of distillation will provide adequate agent. The multistage distillation equipment would be larger, more complicated, more expensive, and as mentioned, require more heat than flash distillation equipment. Thus, its products must perform much better than the flash equipment products, or its use would not be justified. Resolving the issue should involve fog production with products of different types of distillation units, with design and cost estimates made for the most promising.

<u>Task II</u> - Task II was to prepare samples of JP-8 fractions for laboratory evaluations to determine the percentage of light ends that need to be removed. In order to investigate a possible worst case, four different JP-8 fuels were fractionated with distillation end points ranging from approximately 250° to 300°C. Results of recent JP-8 surveys have shown this range of end points to be representative of those fuels currently produced. These four fuels were fractionated into 0- to 40-, 40- to 60-, 60- to 80-, and 80- to 100-percent fractions of the base fuel. TABLE 3 summarizes the distillation results obtained from the four JP-8 fuels and the 80- to 100-percent fractions. The table also includes distillation results from the MIL-F-46162C reference fuel. Full D 2887 distillation data are also shown in the Appendix.

<u>*Fractionation Apparatus*</u> - The glass vacuum distillation apparatus used was from a standard D 2892 procedure. This apparatus is a 15-theoretical plate unit that can distill up to 12 liters per batch. This apparatus consists of:

1. 12-liter - 3-neck glass round bottom flask
2. 120 cm (4 ft), 50-mm diameter vacuum-jacketed column packed with No. 2918 Helipak coils

TABLE 3. ASTM D 2887 Distillation of Test Fuels

	JP-8 - No. 1		JP-8 - No. 2		JP-8 - No. 3		JP-8 - No. 4		
	Neat	Fraction*	Neat	Fraction	Neat	Fraction	Neat	Fraction	DF-2
Initial Boiling Point†, °C	117	209	104	215	118	217	118	217	120
10% Recovered, °C	178	234	176	239	177	245	176	248	182
50% Recovered, °C	216	258	216	263	217	265	214	272	281
90% Recovered, °C	255	279	258	284	263	291	268	302	360
End Point (99%), °C	284	306	285	306	306	332	310	328	415

* The 80- to 100-percent distillation fraction from the neat fuels.
† Temperature for 0.1 percent (wt%) distilled off.

3. Distillate head with magnetically controlled swinging bucket for variable reflux ratios and an integral condenser, all of which are vacuum jacketed
4. Product receiver of 1-liter capacity, vacuum jacketed with integral cooling coils
5. Heating mantle
6. Heating mantle for column
7. Chiller for both condenser and product receiver
8. Powerstats for temperature control
9. Vacuum pump and McLeod gauge
10. Ten-position thermocouple readout

The procedure that was followed consisted of introducing 8 to 10 liters of fuel into the 12-liter flask, and the vacuum was varied from 100 mm Hg down to 1 mm Hg. After degassing, heat is applied. When distillate begins to condense down the column, the reflux ratio is set (generally 5:1). This procedure produces approximately 1 liter/hr of product, which is collected into a graduated receiver. These fractions were collected on a volume basis.

Sample Analysis - The four fractions from each fuel were collected in 1-gal. cans and sealed for future evaluations. The results of boiling point distribution evaluations

(D 2887) are provided in the Appendix. There are two curves for each sample, these being the initial base fuel and the 80- to 100-percent fractions. It is readily apparent that a reasonably good separation was obtained and that these fractions did contain only the heavier, higher boiling materials. The results of the smoke/obscuration evaluations (discussed later) indicated only minimal smoke produced from the 0- to 40-, 40- to 60-, and 60- to 80-percent fractions and reasonable smoke produced from the 80- to 100-percent fraction when compared to diesel fuel. Therefore, only the 80- to 100-percent fractions were considered for further testing.

Task III - Obscuration and persistency measurements were conducted on selected fractions from the four reference fuels using the laboratory apparatus previously developed at BFLRF.(2) In order to assure a direct comparison between samples, all the test parameters were maintained constant. These parameters include fluid flow rate, evaporation surface temperature (exhaust), and dilution air temperature.

The BFLRF bench-test apparatus shown in Fig. 8 consists of a gasoline-powered Briggs and Stratton engine fitted with an exhaust assembly (evaporation chamber). This assembly consisted of a 1-in. (2.5-cm) diameter by 11.75-in (29.8-cm) length conduit tubing that serves as the reaction chamber. This reaction chamber discharged into a 14-in. (35.6-cm) diameter by 10-ft (3.05-m) length of piping. The engine was operated at approximately 1000 rpm and the temperature of the exhaust was approximately 1000°F (538°C) at the point of sample injection.

A generator placed a 200-watt load on the engine for temperature and speed control. A positive displacement pump was used to feed the JP-8 fraction at a constant flow of 6 mL per minute into the hot engine exhaust for vaporization when the temperature reached 1000°F (538°C). An exhaust fan assists the smoke (fog) that is generated to flow past a photocell at a relatively constant rate. The data from the obscurancy measurements and temperature profiles are sent to a data acquisition-reduction system.

The photocells are calibrated before and after testing in order to assure that photocell drift has not occurred. This procedure is accomplished using standard obscuration filters developed

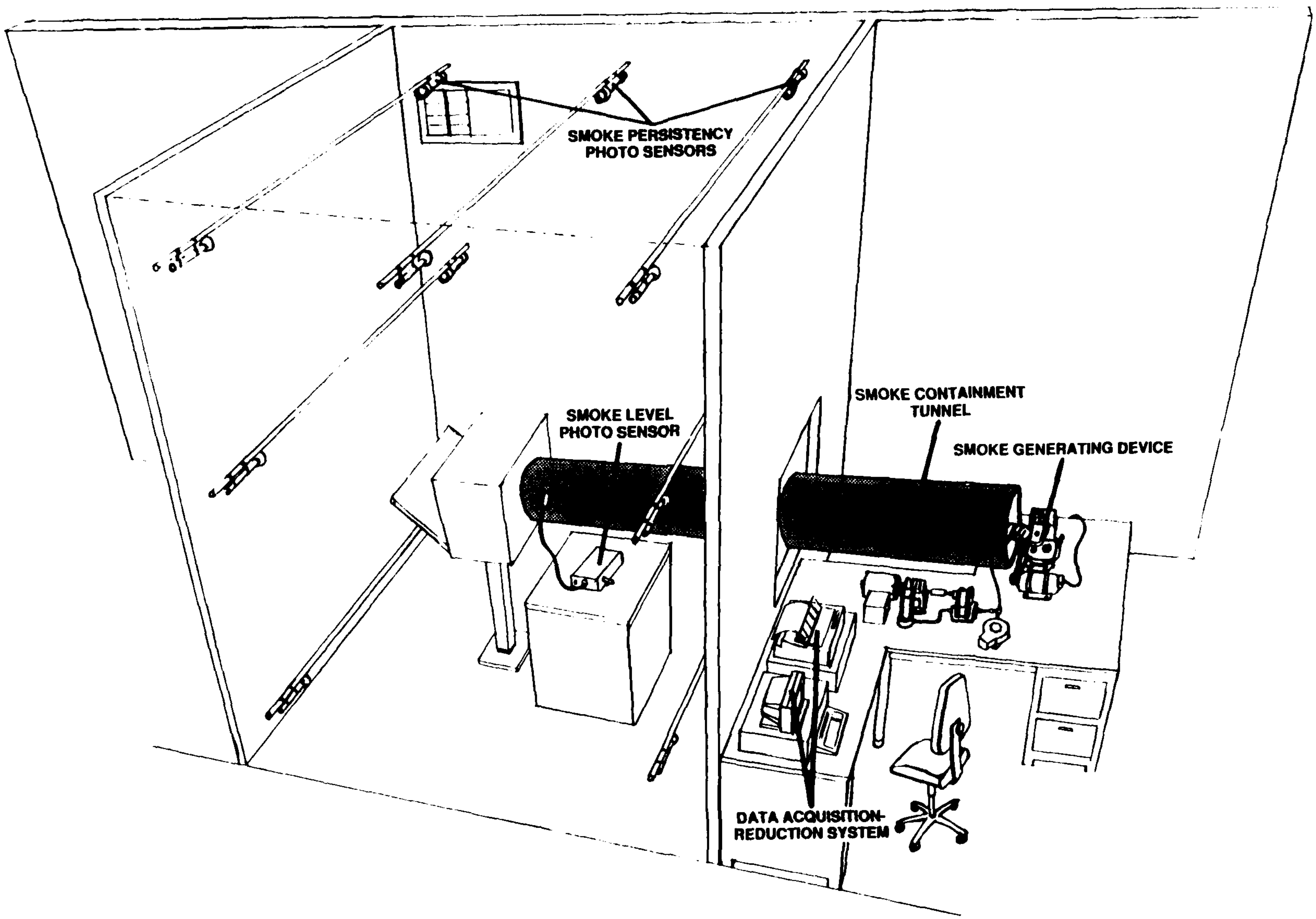

Figure 8. BFLRF smoke obscuration test facility

and used in EPA exhaust measurements. Results of a typical calibration are shown in Fig. 9. The value of this calibration is that it not only assures test-to-test repeatability but also ties the test results to a recognized industry standard.

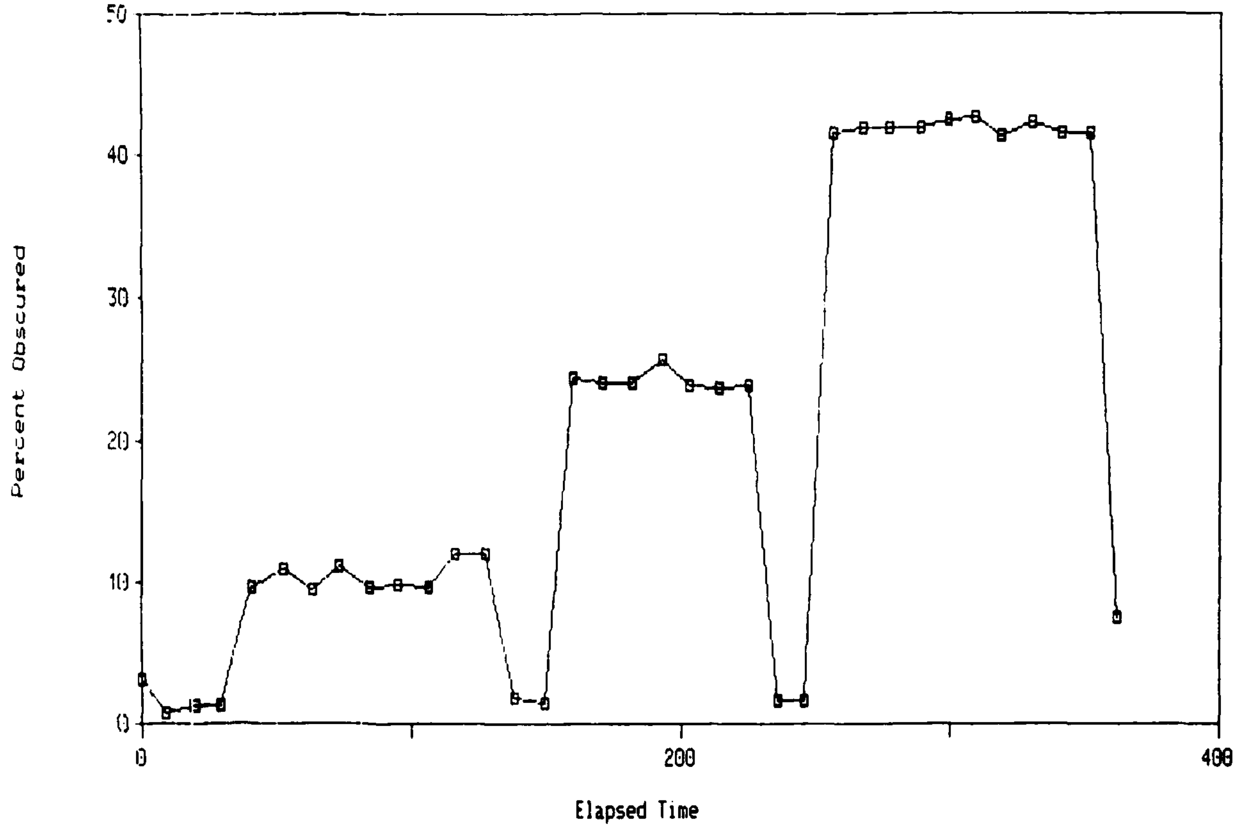

Figure 9. <u>Baseline test - Photocell 8</u>

Obscuration test results are presented in TABLE 4 and, for purposes of comparison, all of the readings are normalized against DF-2, which is shown at 100 percent.

These results show that the amount of smoke formed by the heavy fraction (80 to 100 percent) can be equivalent to the amount of smoke produced by equal volumes of DF-2 in some cases.

Persistency measurements were recorded for each of the 80- to 100-percent fractions from the four test fuels. The procedure that was followed, essentially, consisted of running the same smoke-generating process that is utilized in the obscuration test procedure until the smoke chamber is filled with smoke, as determined by the series of smoke opacity meters placed in

TABLE 4. Obscuration of JP-8 Fractions

Sample	Obscuration, %
DF-2	100.0
JP-8	3.2
Fuel 1	--*
Fraction - 40 percent	--
Fraction - 40 to 60 percent	--
Fraction - 60 to 80 percent	--
Fraction - 80 to 100 percent	55.5
Fuel 2	8.7
Fraction - 0 to 40 percent	--
Fraction - 40 to 60 percent	--
Fraction - 60 to 80 percent	--
Fraction - 80 to 100 percent	81.5
Fuel 3	8.0
Fraction - 0 to 40 percent	--
Fraction - 40 to 60 percent	--
Fraction - 60 to 80 percent	--
Fraction - 80 to 100 percent	91.1
Fuel 4	13.2
Fraction - 0 to 40 percent	--
Fraction - 40 to 60 percent	--
Fraction - 60 to 80 percent	--
Fraction - 80 to 100 percent	102.5

* Obscuration readings below 5 percent.

the room. The positioning arrangement of these photocells are also shown in Fig. 8. The photocells are calibrated using the same procedure as described in the obscuration procedure, and this procedure is routinely accomplished prior to initiation of testing. The calibration and smoke persistency decay as determined by the photocell detector are recorded on computer disks for data reduction procedures at some later time. Fig. 10 shows the results that were obtained when the decay rates were recorded for the 80- to 100-percent fractions from the four JP-8 fuels that were fractionated. These results are compared directly to DF-2, also shown in Fig. 10. The curves presented in this figure are of the following fluids:

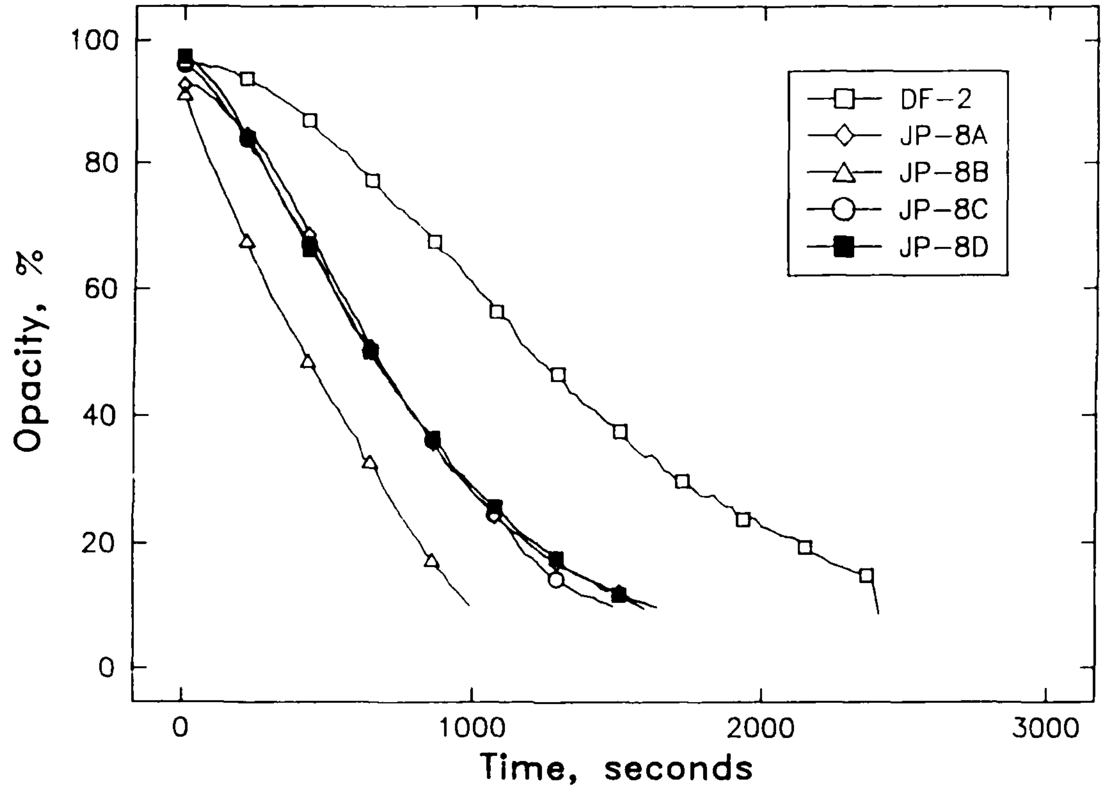

Figure 10. VEESS persistency

1) DF-2 - Reference diesel fuel used throughout the study for a direct comparison
2) JP-8A - The 80- to 100-percent fraction from JP-8 Sample 1
3) JP-8B - The 80- to 100-percent fraction from JP-8 Sample 2
4) JP-8C - The 80- to 100-percent fraction from JP-8 Sample 3
5) JP-8D - The 80- to 100-percent fraction from JP-8 Sample 4

Results of this series of tests showed that, according to this procedure, the persistency of the heavy fractions of JP-8 was still below DF-2 by perhaps 50 percent. The real meaning of these evaluations is not completely understood and must still be compared to field tests before these results can be completely interpreted.

B. Phase II - Induction/Combustion Study

The induction/combustion studies were an extension of earlier CRDEC-funded work (3-6) wherein a sooting concept was studied to improve JP-8 fog production. Previous BFLRF studies (7) showed that a minimum of 50 percent of a smoke-producing agent (i.e., oils, etc.) in JP-8 was required to produce acceptable smoke in laboratory engine exhaust. This feed rate of 0.5 gal./min fogging agent is considered an unacceptable logistics burden. However, a feed rate of 0.05 gal./min might be acceptable. The current work investigated the induction/combustion processes by introducing JP-8 with small amounts of Petroleum, Oils, and Lubricants (POL) candidates (i.e., less than 5 percent) into the engine intake air system and/or engine fuel system. This approach was expected to increase the soot-loading characteristics of combusted JP-8, thereby increasing the number of nucleation sites in the engine exhaust for fog droplets. It was believed that increasing the particulate in the exhaust, while injecting JP-8 (or JP-8 heavy ends) in the exhaust, would produce adequate smoke with JP-8.

The induction portion of this approach consisted of fumigating JP-8/POL candidates into the engine intake airstream. Two events were expected to occur as a result of the fumigation. The first event is the partial combustion of the JP-8/POL candidates, resulting in the heavier hydrocarbons causing increased particulates. The unburned fractions would be in the form of finely atomized/vaporized particles. These changes in the intake airstream could be important for heavier POL products such as lubricating oils in that their smoke yield is increased. The second event that would occur, although possibly insignificant, is the fine atomization of a small amount of JP-8/POL candidates as a result of engine valve overlap and dilution or scavenge airflow. This possibility was also expected to increase the smoke yield of fumigants such as the heavier POL products, e.g., lubricating oils.

The combustion approach consisted of directly injecting POL candidates into the engine with the fuel. The result of this injection was expected to be increased particulates, especially with the heavier POL candidates. Also expected were some finely atomized unburned hydrocarbons, which would condense upon exiting the exhaust system.

The induction/combustion experiments were screened with a 45-kW generator, powered by a Detroit Diesel 3-71N. For the induction portion of the experiment, the JP-8/POL blends were

fumigated into the engine at the blower inlet. There was some concern as to how much liquid could be fumigated into the intake air before operational problems occurred. Historical data on engine interferants (8) indicated that 4 wt% of the total intake charge (air and fuel) of n-heptane was enough to restrict the operation of a diesel engine. To remain safe, a 2-wt% limit was imposed on the Detroit Diesel 3-71N for JP-8 induction studies. This safe flow was determined to be 270 mL/min at 1800 rpm, full load. During the induction studies, 270 mL/min of JP-8 or JP-8 containing 5 percent POL were fumigated into the engine, while 330 mL/min of JP-8 were introduced into the VEESS.

For the combustion studies, a blend of 5 percent POL with JP-8 was used as the engine fuel, in combination with 330 mL/min of JP-8 used in the VEESS. The POL product used for the studies was a MIL-L-2104D 30-weight tactical engine oil, chosen for its obscuration and persistency performance in an earlier study.(7)

The generator set was instrumented with rotameters for introduction of smoke agents into the exhaust stream and into the intake air to complete the experiments shown in Fig. 11. The generator set was loaded with a resistive load bank and operated at a synchronous speed of 1800 rpm. The experiments were video recorded for subjective evaluations of the smoke-producing capabilities of the alternative smoke concepts. Results of these studies are summarized in TABLE 5.

The generator engine was initially fueled with JP-8 while DF-2 was introduced into the exhaust to obtain a reference level for obscuration with the VEESS. The next step was to introduce JP-8 into the exhaust, which revealed the inadequacies of the evaporation/condensation process for smoke development when using JP-8. As expected, the simulator operating on JP-8 did not produce visible smoke. The next experiment involved using JP-8 heavy ends in the VEESS. The heavy ends chosen were JP-8D, the heaviest of the four partially distilled JP-8 heavy fractions, and the fraction that displayed the best obscuration performance in the single-cylinder VEESS simulator. The JP-8D heavy ends displayed smoke-producing capabilities that were subjectively equal to the DF-2 produced smoke. Due to wind conditions during testing, it was difficult to detect any difference in persistency between DF-2 and JP-8D heavy ends when used in the diesel VEESS simulator.

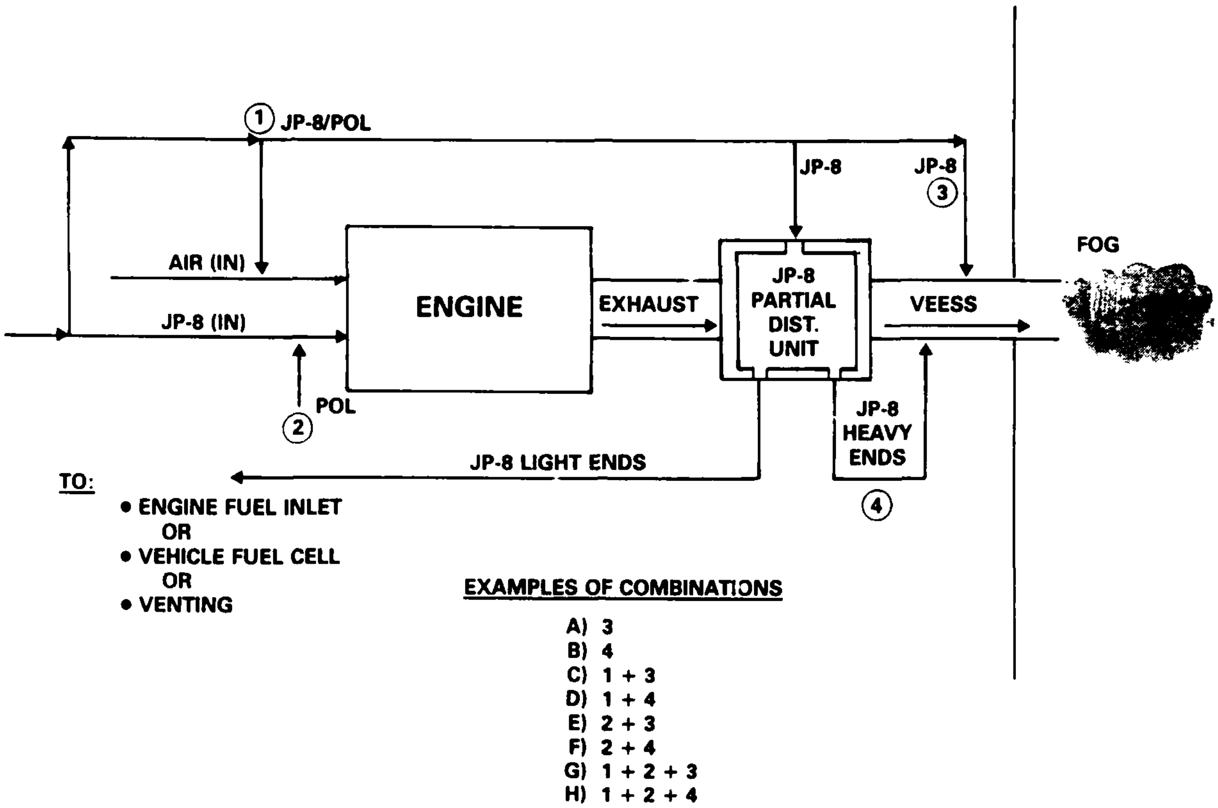

Figure 11. Apparatus for partial JP-8 distillation and/or induction/combustion studies in 45-kW diesel generator

TABLE 5. Summary of Induction/Combustion Studies

Test No.	Combustion	Induction	VEESS	Test Results
1	JP-8		DF-2	Baseline smoke
2	JP-8		JP-8	No Smoke
3	JP-8		JP-8D*	Similar to Test No. 1
4	JP-8	95% JP-8 + 5% POL		Similar to Test No. 2
5	JP-8	95% JP-8 + 5% POL	JP-8	Similar to Test No. 2
6	JP-8	95% JP-8 + 5% POL	JP-8D*	Similar to Test No. 1
7	95% JP-8 + 5% POL	95% JP-8 + 5% POL	JP-8	Similar to Test No. 2
8	95% JP-8 + 5% POL		JP-8D	Similar to Test No. 1
9	95% JP-8 + 5% POL	95% JP-8 + 5% POL	JP-8	Similar to Test No. 2

* 80 to 100 percent distillation fraction from JP-8D.

The next experiment involved introducing 95 percent JP-8/5 percent POL into the intake airstream, while JP-8 was being introduced into the VEESS. The experiment was performed in two stages. The first stage introduced the JP-8/POL into the intake with the VEESS flow turned off to determine any qualitative increase in soot level, if any, in the exhaust. The results indicated no increase in soot loading due to the JP-8/POL in the intake air. The second stage involved introducing JP-8 into the VEESS, while JP-8/POL was being aspirated into the intake air. The subjective evaluations indicated no obscuration increase when compared to JP-8 VEESS results.

An experiment was performed with JP-8/POL in the intake and JP-8D heavy ends introduced into the VEESS. The evaluations indicated that the JP-8D heavy ends produced smoke of equal obscurant levels as DF-2, but there was no noticeable increase due to the aspiration of the JP-8/POL into the intake air. Also, any persistency increase due to the JP-8/POL aspiration could not be evaluated due to the climatic conditions.

The next series of experiments involved burning JP-8/POL as the fuel and introducing either JP-8 or JP-8D heavy ends into the VEESS. The test with JP-8 in the VEESS indicated no increase of soot due to the combustion of JP-8/POL in the engine, thus there was no obscuration improvement with JP-8 in the VEESS. The test with JP-8D heavy ends in the VEESS and JP-8/POL as the fuel revealed obscuration performance equivalent to DF-2; however, no obscuration improvement that could be attributed to the JP-8/POL combusted in the engine was noted. Once again the climatic conditions prevented any comparisons of persistency between the JP-8D heavy ends combined with JP-8/POL combustion and DF-2.

The final trial involved combusting JP-8/POL as the fuel, aspirating JP-8/POL into the intake air, and introducing JP-8 fuel in the VEESS. As was performed earlier, the JP-8/POL was combusted and aspirated into the engine with the VEESS flow turned off to determine if there was any increase in the formation of soot. The evaluations indicated no qualitative increase of the exhaust particulate due to the induction/combustion of the JP-8/POL. When the VEESS flow was initiated, no improvement in obscuration was noted with JP-8 in the VEESS due to the induction/combustion of the JP-8/POL. The case in which (1) JP-8/POL was combusted as the fuel, (2) JP-8/POL was aspirated into the intake air, and (3) JP-8D heavy ends were introduced in the VEESS was not attempted due to the exhaustion of the

JP-8D heavy ends supply during the previous experiments. However, it is felt the results would have been identical to the previous tests when JP-8D heavy ends were introduced into the VEESS.

The results summarized in TABLE 5 indicate that smoke of adequate obscuration, subjectively equivalent to DF-2, can be produced in a multicylinder diesel VEESS simulator when JP-8D heavy ends are introduced into the VEESS. The persistency performance with the diesel simulator using JP-8D heavy ends could not be evaluated due to the ambient weather conditions. The effect of increasing nucleation sites to stimulate condensation for fog cloud formation could not be determined because it was apparent the soot loading in the engine exhaust was not increased with the induction/combustion of the JP-8/POL.

IV. CONCLUSIONS AND RECOMMENDATIONS

The results of these studies indicate that the potential may exist to separate an acceptable smoke-producing agent from JP-8 fuel. Laboratory tests conducted on some of the 80- to 100-percent distilled fraction (bottoms) from JP-8 appeared to provide similar obscuration values to DF-2 when evaluated under similar conditions. The laboratory tests indicated, however, that the persistency of the heavy fractions of JP-8 was still below DF-2 by approximately 50 percent. When subjectively evaluated in the open environmental test facility (diesel generator), the distilled fraction (bottoms) from JP-8 appeared to remain as a smoke for the same period of time as the diesel fuel. It is felt that the recycled, more volatile evaporated fraction of JP-8 could be burned in the turbine-powered M1A1 family of vehicles; however, the acceptability of this fraction for use in the diesel-powered M60/M88 and M2/M3 vehicle families is not known. Attempts to enhance the persistency or the amount of smoke produced by increasing the concentration of soot in the exhaust were unsuccessful. The effort to increase the soot involved combustion of small concentrations of heavy fluids, such as 5 vol% of 30-wt crankcase lubricant in the fuel; however, either the soot was too small to see or no soot particles were produced. In any case, no improvement was observed in the quality of smoke that was produced. There is the possibility that soot loading may be enhanced in four-cycle diesel or turbine combustion systems, or perhaps with increased induction rates in two-cycle diesel engines.

Results of computer program studies to calculate the size requirements for a flash evaporator to fractionally distill the heavy ends for JP-8 showed a reasonable size unit is required (~ 10 in. × 30 in.); however, the heat exchanger to heat the fuel prior to distillation may prove to be unacceptable.

A recommendation is made that the heat exchanger/flash evaporator be designed to include a small retention chamber. This chamber would substantially reduce the required size of the unit as well as have readily available smoke agent for an instant response.

It is also possible that by removing the heat from the exhaust in the distillation process, the amount of superheat of the fluid vapors could be reduced, thereby enhancing the fog nucleation, condensation process.

V. REFERENCES

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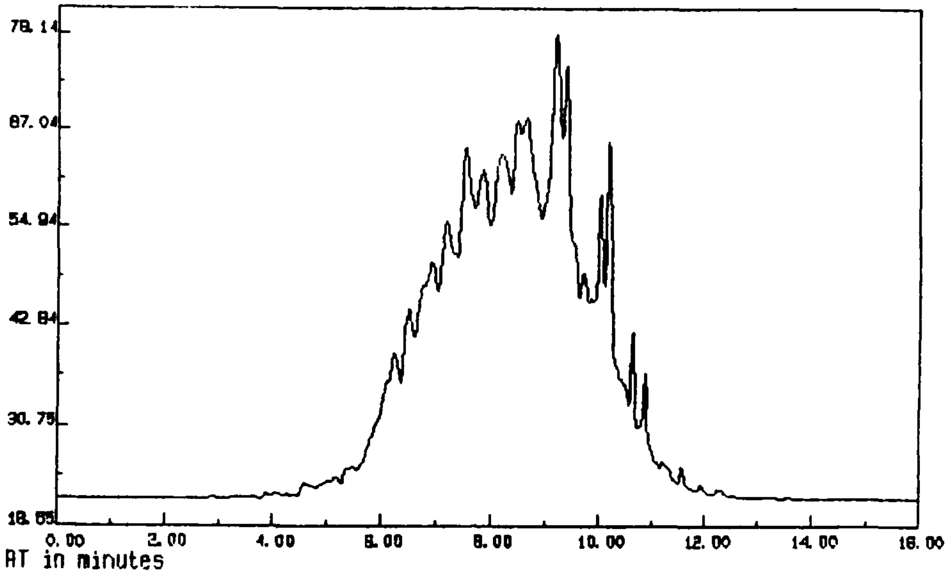
APPENDIX

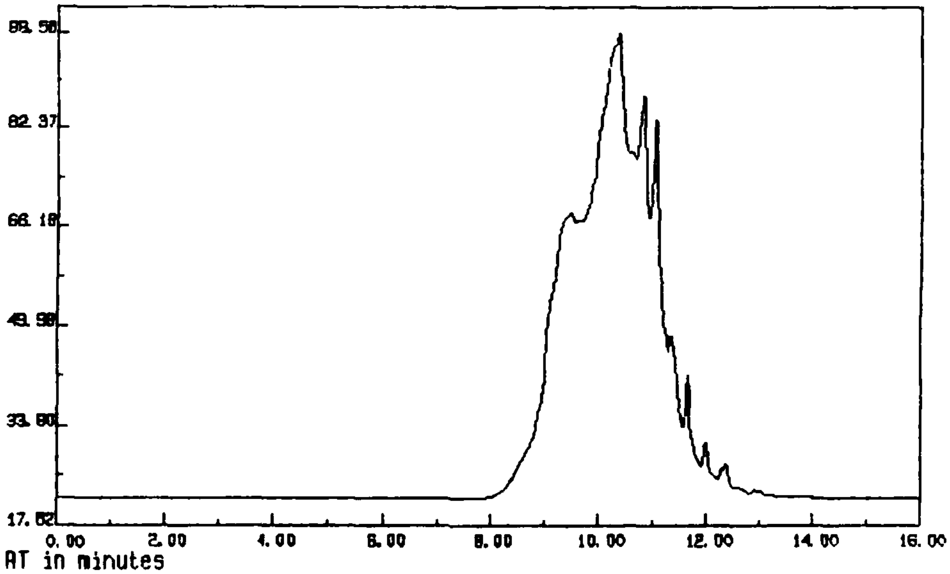
Boiling Point Distributions



SAMPLE: BLEND 1 TOP INJECTED AT 12:24:14 ON OCT 10, 1989
Meth: SD/FUL Raw: BL1TOP Proc: *PRC03

Figure A-1. <u>Fuel No. 1</u>

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	117.5	28	198.8	64	229
.2	124.5	29	199.4	65	229.8
.3	132	30	200.7	66	230.6
.4	134.3	31	201.3	67	231.3
.5	136.5	32	202	68	232.1
.6	139.5	33	203.2	69	232.8
.7	141.8	34	203.9	70	233.6
.8	143.3	35	204.5	71	233.6
.9	144.8	36	205.1	72	234.4
1	146.3	37	205.8	73	235.1
2	157.2	38	207.1	74	235.9
3	162.8	39	207.7	75	236.7
4	165.7	40	209	76	237.4
5	168.5	41	209.6	77	238.2
6	170.6	42	210.3	78	239.7
7	172.7	43	210.9	79	240.5
8	174.1	44	211.5	80	242
9	176.4	45	212.2	81	243.5
10	177.8	46	213.5	82	245.1
11	179.3	47	214.1	83	245.8
12	180.8	48	214.7	84	247.4
13	182.2	49	215.4	85	248.9
14	183.7	50	216	86	250.4
15	184.5	51	216.8	87	252
16	185.9	52	217.6	88	252.7
17	187.4	53	218.3	89	254.2
18	188.9	54	219.1	90	255
19	189.6	55	219.9	91	255.8
20	191.1	56	220.6	92	257.3
21	191.8	57	222.1	93	259.6
22	193.3	58	222.9	94	261.9
23	194	59	223.7	95	265
24	195.5	60	224.4	96	267.3
25	196.8	61	225.2	97	271.1
26	197.5	62	226.7	98	275.1
27	198.1	63	227.5	99	283.8
				99.5	293.3
				100	383.8



SAMPLE: BLEND 1 BTM INJECTED AT 13:33:43 ON OCT 10. 1989
Meth: SD/FUL Raw: BL1BTM Proc: *PRC03

Figure A-2. **<u>80- to 100-percent fraction from fuel No. 1</u>**

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	209	28	246.6	64	264.2
.2	211.5	29	247.4	65	265
.3	213.5	30	247.4	66	265
.4	214.1	31	248.1	67	265.7
.5	215.4	32	248.9	68	266.5
.6	216	33	249.7	69	267.3
.7	216.8	34	250.4	70	267.3
.8	217.6	35	250.4	71	268
.9	217.6	36	251.2	72	268.8
1	218.3	37	252	73	268.8
2	222.1	38	252	74	269.5
3	225.2	39	252.7	75	270.3
4	227.5	40	253.5	76	270.7
5	229	41	253.5	77	271.1
6	230.6	42	254.2	78	271.8
7	231.3	43	255	79	272.4
8	232.1	44	255	80	273.1
9	232.8	45	255.8	81	273.1
10	233.6	46	255.8	82	273.8
11	234.4	47	256.5	83	274.4
12	235.1	48	256.5	84	275.1
13	235.9	49	257.3	85	275.1
14	236.7	50	258.1	86	275.8
15	237.4	51	258.1	87	276.4
16	238.2	52	258.8	88	277.1
17	239	53	258.8	89	278.4
18	239.7	54	259.6	90	279.1
19	240.5	55	259.6	91	280.5
20	240.5	56	260.4	92	281.8
21	241.3	57	260.4	93	282.5
22	242	58	261.1	94	284.5
23	242.8	59	261.9	95	286.5
24	243.5	60	261.9	96	288.7
25	244.3	61	262.7	97	292.5
26	245.1	62	263.4	98	297.8
27	245.8	63	263.4	99	306.1
				99.5	316.6
				100	384.6

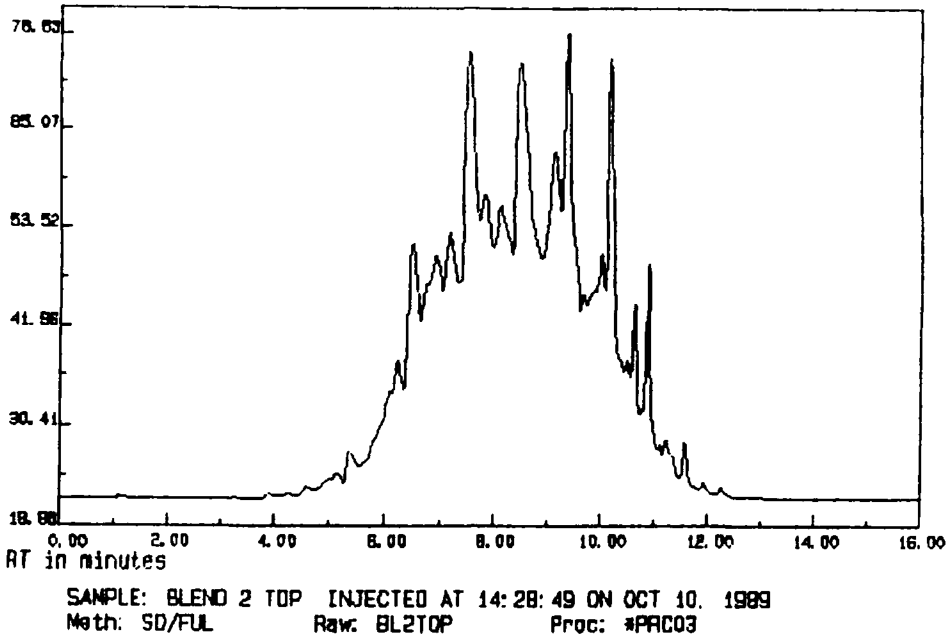
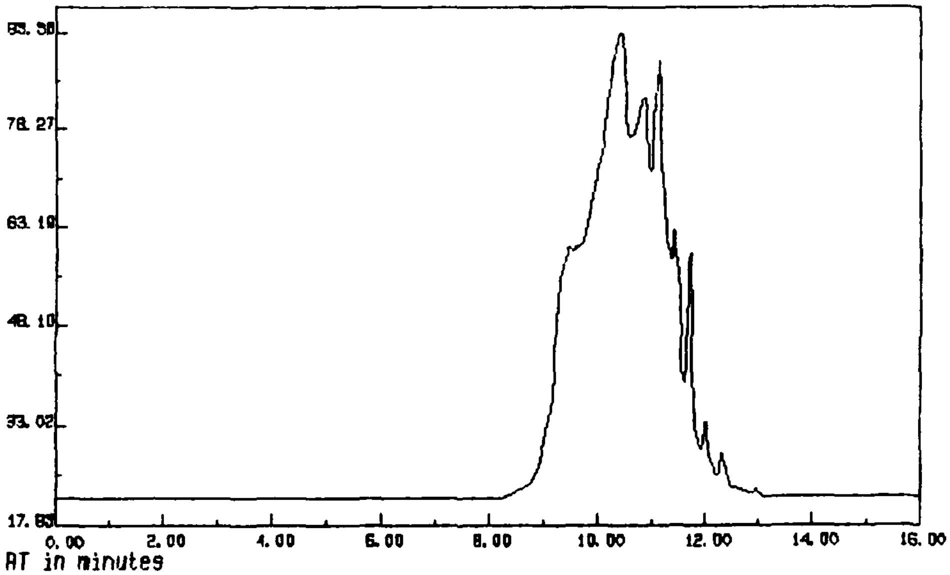


Figure A-3. <u>**Fuel No. 2**</u>

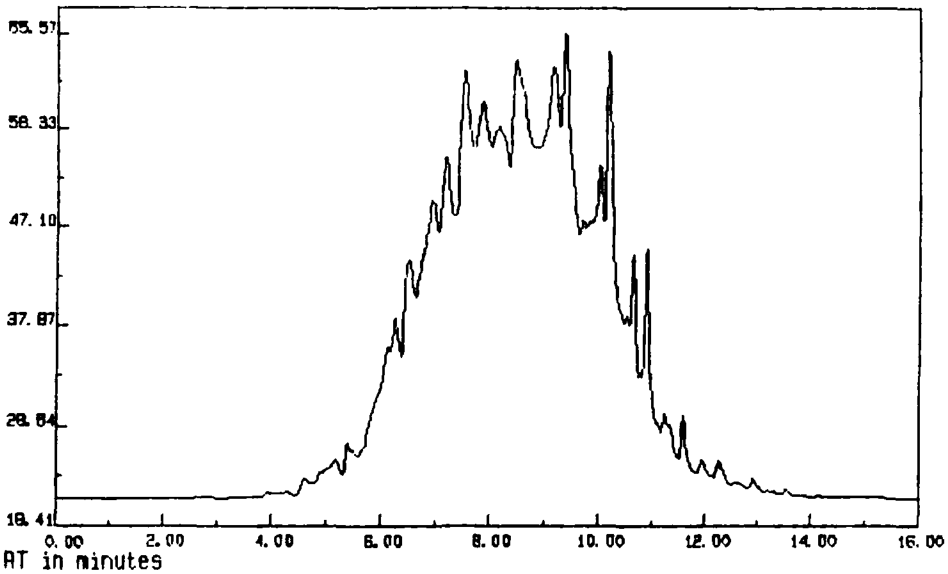
WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	103.6	28	198.1	64	229.8
.2	119.8	29	198.8	65	230.6
.3	126.8	30	198.8	66	231.3
.4	132.8	31	199.4	67	232.1
.5	135	32	200	68	232.8
.6	138	33	201.3	69	234.4
.7	140.3	34	202	70	235.1
.8	142.6	35	202.6	71	235.9
.9	144.1	36	203.9	72	236.7
1	145.6	37	204.5	73	237.4
2	154.4	38	205.1	74	238.2
3	161.4	39	206.4	75	239
4	165	40	207.7	76	239.7
5	167.8	41	208.3	77	241.3
6	169.9	42	209	78	242.8
7	172	43	210.3	79	244.3
8	174.1	44	210.9	80	245.8
9	175.6	45	212.2	81	247.4
10	176.4	46	212.8	82	248.9
11	177.8	47	214.1	83	250.4
12	179.3	48	214.7	84	251.2
13	180.8	49	215.4	85	252.7
14	182.2	50	216	86	254.2
15	183.7	51	216.8	87	255
16	184.5	52	217.6	88	255.8
17	185.9	53	218.3	89	256.5
18	187.4	54	219.1	90	258.1
19	188.9	55	219.9	91	260.4
20	189.6	56	220.6	92	262.7
21	191.1	57	221.4	93	265
22	191.8	58	222.9	94	266.5
23	193.3	59	223.7	95	269.6
24	194.8	60	225.2	96	271.8
25	196.2	61	226	97	273.1
26	196.8	62	227.5	98	278.4
27	197.5	63	228.3	99	285.1
				99.5	293.3
				100	384.6



SAMPLE: BLEND 2 BTM INJECTED AT 15:20:40 ON OCT 10, 1989
Meth: SD/FUL Raw: BL2BTM Proc: #PRC03

Figure A-4. 80- to 100-percent fraction from fuel No. 2

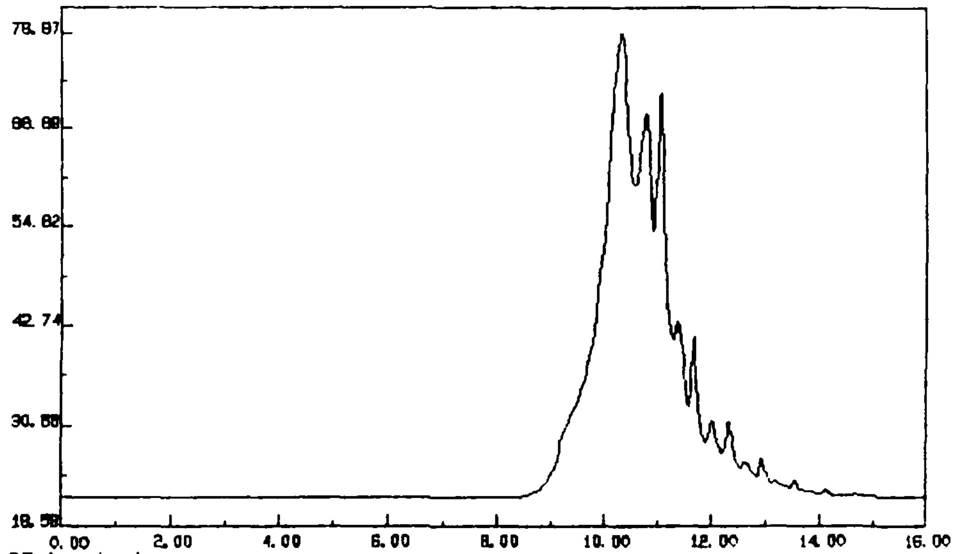
WT% OFF	DEG C
.1	215.4
.2	218.3
.3	220.6
.4	222.1
.5	223.7
.6	224.4
.7	225.2
.8	226
.9	226.7
1	226.7
2	230.6
3	232.8
4	233.6
5	235.1
6	235.9
7	236.7
8	237.4
9	238.2
10	239
11	239.7
12	240.5
13	241.3
14	242
15	242.8
16	243.5
17	244.3
18	245.1
19	245.8
20	246.6
21	247.4
22	248.1
23	248.9
24	249.7
25	250.4
26	251.2
27	251.2
28	252
29	252.7
30	253.5
31	253.5
32	254.2
33	255
34	255
35	255.8
36	256.5
37	256.5
38	257.3
39	257.3
40	258.1
41	258.8
42	258.8
43	259.6
44	259.6
45	260.4
46	260.4
47	261.1
48	261.9
49	261.9
50	262.7
51	262.7
52	263.4
53	264.2
54	264.2
55	265
56	265.7
57	266.5
58	266.5
59	267.3
60	268
61	268
62	268.8
63	269.6
64	269.6
65	270.3
66	271.1
67	271.1
68	271.8
69	272.4
70	272.4
71	273.1
72	273.8
73	274.4
74	274.4
75	275.1
76	275.8
77	275.8
78	276.4
79	276.4
80	277.1
81	277.8
82	278.4
83	279.1
84	279.8
85	280.5
86	281.1
87	281.8
88	282.5
89	283.1
90	283.8
91	284.5
92	285.8
93	287.2
94	287.9
95	289.5
96	291.7
97	294.8
98	299.4
99	306.1
99.5	319.7
100	384.6



SAMPLE: BLEND 3 TOP INJECTED AT 8:52:15 ON OCT 11, 1989
Meth: SD/FUL Raw: BL3TOP Proc: #PRC03

Figure A-5. Fuel No. 3

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	118.3	28	198.8	64	232.1
.2	125.2	29	200	65	232.8
.3	131.3	30	200.7	66	233.6
.4	134.3	31	201.3	67	234.4
.5	136.5	32	202.6	68	235.1
.6	138.8	33	203.2	69	236.7
.7	140.3	34	203.9	70	237.4
.8	141.8	35	205.1	71	238.2
.9	143.3	36	205.8	72	239
1	144.1	37	206.4	73	240.5
2	153.7	38	207.7	74	241.3
3	160	39	208.3	75	242.3
4	164.2	40	209	76	244.3
5	167.1	41	210.3	77	245.8
6	169.2	42	210.9	78	246.6
7	171.3	43	211.5	79	248.1
8	173.4	44	212.3	80	249.7
9	175.6	45	213.5	81	251.2
10	177.1	46	214.7	82	252
11	178.6	47	215.4	83	253.5
12	180	48	216	84	254.2
13	181.5	49	216.8	85	255.8
14	183	50	217.6	86	256.5
15	184.5	51	218.3	87	257.3
16	185.9	52	219.9	88	259.6
17	187.4	53	220.6	89	261.1
18	188.1	54	221.4	90	263.4
19	189.6	55	222.9	91	265.7
20	191.1	56	223.7	92	267.3
21	191.8	57	224.4	93	270.3
22	193.3	58	226	94	271.8
23	194	59	226.7	95	274.4
24	195.5	60	228.3	96	279.1
25	196.8	61	229	97	284.5
26	197.5	62	229.8	98	293.3
27	198.1	63	230.6	99	306.9
				99.5	320.5
				100	384.6

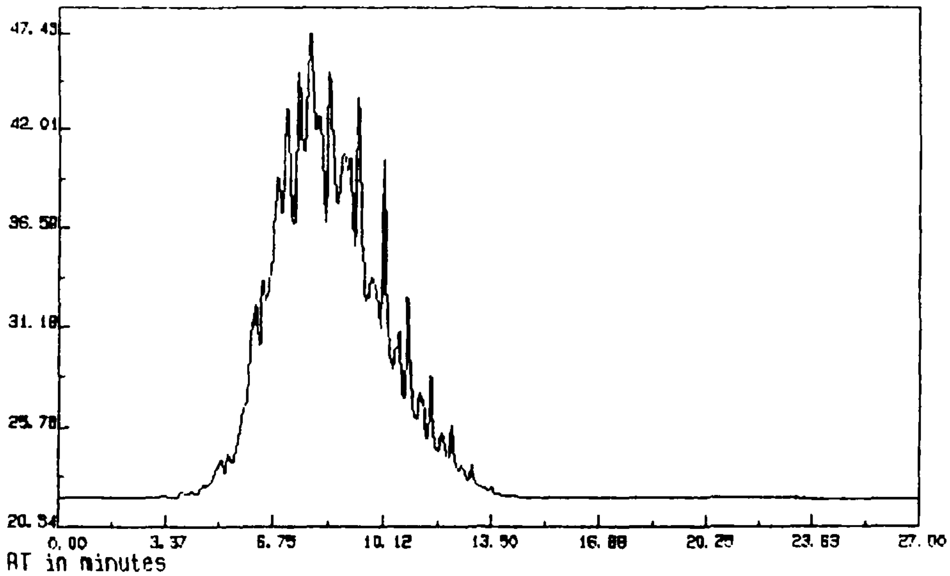


RT in minutes

SAMPLE: BLEND 3 BTM INJECTED AT 14:31:16 ON OCT 13, 1989
Meth: SD/FUL Raw: *RAW03 Proc: *PRC03

Figure A-6. <u>80- to 100-percent fraction from fuel No. 3</u>

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	217.6	28	256.5	64	271.1
.2	221.4	29	256.5	65	271.8
.3	223.7	30	257.3	66	272.4
.4	225.2	31	257.3	67	273.1
.5	226.7	32	258.1	68	273.1
.6	227.5	33	258.1	69	273.8
.7	228.3	34	258.1	70	274.4
.8	229	35	258.8	71	274.4
.9	229	36	258.8	72	275.1
1	229.8	37	259.6	73	275.1
2	233.6	38	259.6	74	275.8
3	235.9	39	260.4	75	275.8
4	237.4	40	260.4	76	276.4
5	239	41	261.1	77	277.1
6	240.5	42	261.1	78	277.8
7	242	43	261.9	79	278.4
8	243.5	44	261.9	80	279.8
9	245.1	45	262.7	81	280.5
10	245.8	46	263.4	82	281.1
11	246.6	47	263.4	83	281.8
12	248.1	48	264.2	84	283.1
13	248.9	49	265	85	283.8
14	249.7	50	265	86	285.1
15	250.4	51	265.7	87	286.5
16	250.4	52	266.5	88	287.9
17	251.2	53	266.5	89	288.7
18	252	54	267.3	90	291
19	252.7	55	267.3	91	294
20	252.7	56	268	92	296.3
21	253.5	57	268.8	93	298.6
22	254.2	58	268.8	94	301.6
23	254.2	59	269.6	95	303.9
24	255	60	269.6	96	308.4
25	255	61	270.3	97	314.4
26	255.8	62	270.3	98	320.5
27	255.8	63	271.1	99	332.8
				99.5	345.8
				100	384.6



SAMPLE: BLEND 4 TOP INJECTED AT 9:16:23 ON OCT 13, 1989
Meth: SD/FUL Raw: BL4TOP Proc: #PRC03

Figure A-7. Fuel No. 4

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	118.3	28	196.8	64	227.5
.2	126.8	29	197.5	65	228.3
.3	132.8	30	198.1	66	229.8
.4	135.8	31	198.8	67	230.6
.5	138.8	32	199.4	68	232.1
.6	140.3	33	200.7	69	232.8
.7	142.6	34	201.3	70	234.4
.8	143.3	35	202	71	235.1
.9	144.8	36	202.6	72	236.7
1	145.6	37	203.2	73	237.4
2	155.1	38	203.9	74	239
3	160.7	39	204.5	75	239.7
4	164.2	40	205.1	76	242
5	166.4	41	206.4	77	243.5
6	168.5	42	207.1	78	245.1
7	169.9	43	207.7	79	246.6
8	172	44	208.3	80	248.1
9	174.1	45	209	81	250.4
10	175.6	46	210.3	82	252
11	177.1	47	210.9	83	253.5
12	178.6	48	211.5	84	255
13	180	49	212.8	85	256.5
14	181.5	50	213.5	86	258.1
15	183	51	214.7	87	261.1
16	183.7	52	215.4	88	263.4
17	185.2	53	216	89	265.7
18	185.9	54	216.8	90	268.8
19	187.4	55	217.6	91	271.1
20	188.1	56	219.1	92	273.1
21	189.6	57	219.9	93	277.1
22	190.3	58	221.4	94	279.8
23	191.1	59	222.1	95	283.8
24	191.8	60	223.7	96	287.2
25	193.3	61	224.4	97	294
26	194.8	62	225.2	98	300.9
27	195.5	63	226.7	99	310.6
				99.5	318.9
				100	384.6

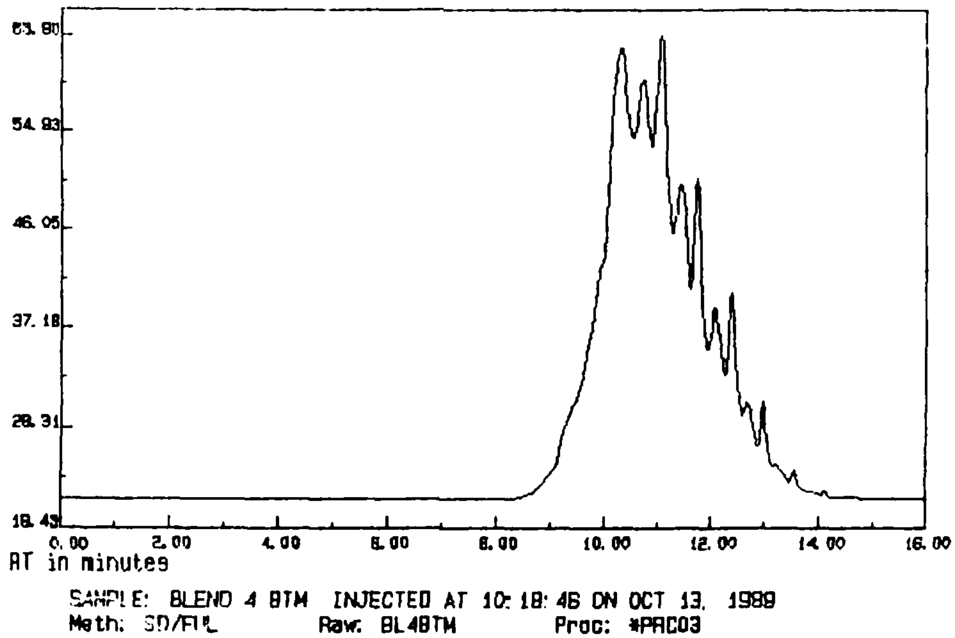
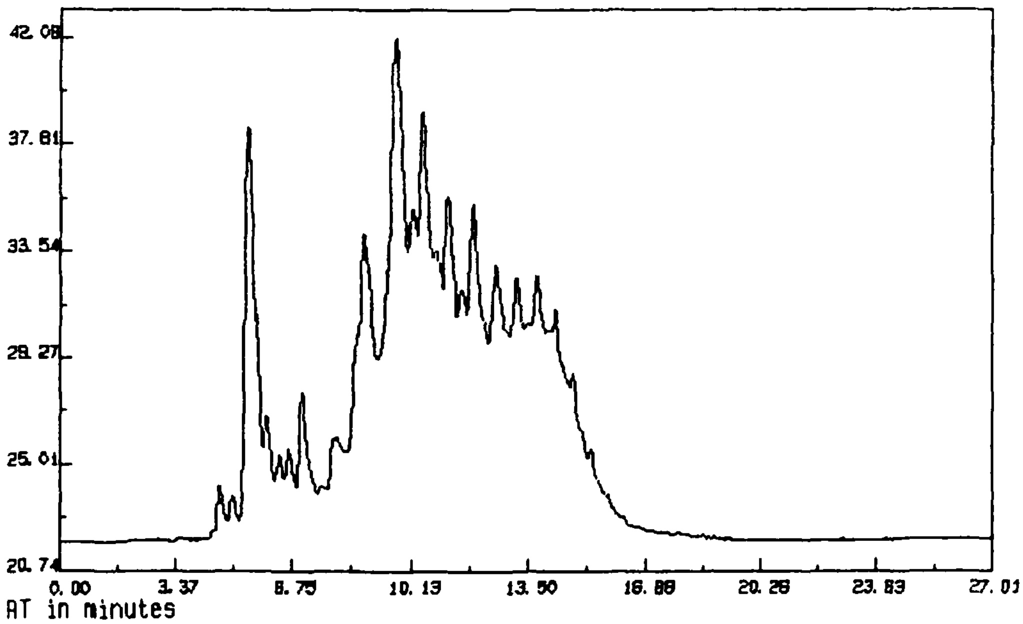


Figure A-8. <u>80- to 100-percent fraction from fuel No. 4</u>

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	216.8	28	259.6	64	278.4
.2	221.4	29	260.4	65	279.1
.3	223.7	30	260.4	66	279.8
.4	225.2	31	261.1	67	280.5
.5	226.7	32	261.9	68	281.1
.6	227.5	33	262.7	69	281.8
.7	228.3	34	262.7	70	282.5
.8	229	35	263.4	71	283.1
.9	229.8	36	264.2	72	283.8
1	230.6	37	265	73	284.5
2	234.4	38	265.7	74	285.1
3	237.4	39	265.7	75	285.3
4	239.7	40	266.5	76	286.5
5	241.3	41	267.3	77	287.9
6	243.5	42	267.3	78	288.7
7	245.1	43	268	79	289.5
8	246.6	44	268.8	80	289.5
9	247.4	45	268.8	81	290.2
10	248.1	46	269.6	82	291.7
11	249.7	47	270.3	83	293.3
12	250.4	48	270.3	84	294
13	251.2	49	271.1	85	295.5
14	252	50	271.8	86	297.1
15	252.7	51	272.4	87	297.8
16	253.5	52	273.1	88	299.4
17	254.2	53	273.1	89	300.9
18	255	54	273.8	90	302.4
19	255	55	274.4	91	303.9
20	255.8	56	274.4	92	304.6
21	256.5	57	275.1	93	306.1
22	256.5	58	275.8	94	308.4
23	257.3	59	275.8	95	310.6
24	258.1	60	276.4	96	313.6
25	258.1	61	276.4	97	316.6
26	258.8	62	277.1	98	320.5
27	258.8	63	277.8	99	328.2
				99.5	334.3
				100	384.6



SAMPLE: AL-15542-F INJECTED AT 16:37:50 ON MAR 9, 1990
Meth: SD/FUL Raw: AL542F Proc: *PRC03

Figure A-9. DF-2 fuel

WT% OFF	DEG C	WT% OFF	DEG C	WT% OFF	DEG C
.1	119.6	28	251.1	64	305.4
.2	133.5	29	252.6	65	306.8
.3	142.3	30	254.1	66	308.2
.4	145.3	31	255.6	67	309.7
.5	146	32	256.4	68	311.9
.6	146.7	33	257.1	69	314
.7	148.2	34	258.6	70	317
.8	148.9	35	259.4	71	318.5
.9	151.1	36	260.9	72	320.8
1	153.3	37	262.4	73	322.3
2	161.4	38	263.9	74	324.6
3	162.9	39	265.4	75	326.9
4	164.4	40	266.9	76	329.2
5	165.9	41	268.4	77	331.5
6	167.3	42	269.9	78	333.8
7	169.5	43	271.3	79	336.1
8	171.8	44	272.8	80	337.6
9	176.2	45	274.2	81	339.9
10	182.1	46	274.9	82	342.9
11	188	47	276.3	83	345.2
12	194.7	48	277.7	84	346.7
13	198.9	49	279.1	85	348.9
14	203.7	50	280.5	86	351.1
15	211.9	51	281.9	87	353.3
16	217.6	52	284.1	88	355.5
17	222.9	53	285.5	89	357.7
18	228.2	54	287.6	90	359.9
19	231.3	55	289.1	91	362.1
20	233.6	56	290.6	92	365
21	235.9	57	292.1	93	368
22	237.4	58	293.6	94	370.9
23	239.7	59	295.8	95	374.6
24	241.2	60	298	96	379
25	243.5	61	299.5	97	384.9
26	246.5	62	301.7	98	393.7
27	248.8	63	303.9	99	415
				99.5	440.1
				100	505.9

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